

GOATS'2000

Multi-scale Environmental Assessment

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LONG-TERM GOAL

Develop environmentally adaptive bi- and multi-static sonar concepts for autonomous underwater vehicle networks for detection and classification of proud and buried targets in very shallow water.

OBJECTIVES

The objective of the environmental assessment component of the GOATS project is to develop integrated observation and modeling concepts for rapid environmental assessment of the shallow and very shallow water environment. Combining state-of-the-art adaptive observation capabilities of the autonomous oceanographic sampling network (AOSN) with oceanographic modeling and data assimilation concepts a nested environmental forecasting paradigm is developed, providing multi-scale environmental estimates for littoral mine countermeasures.

APPROACH

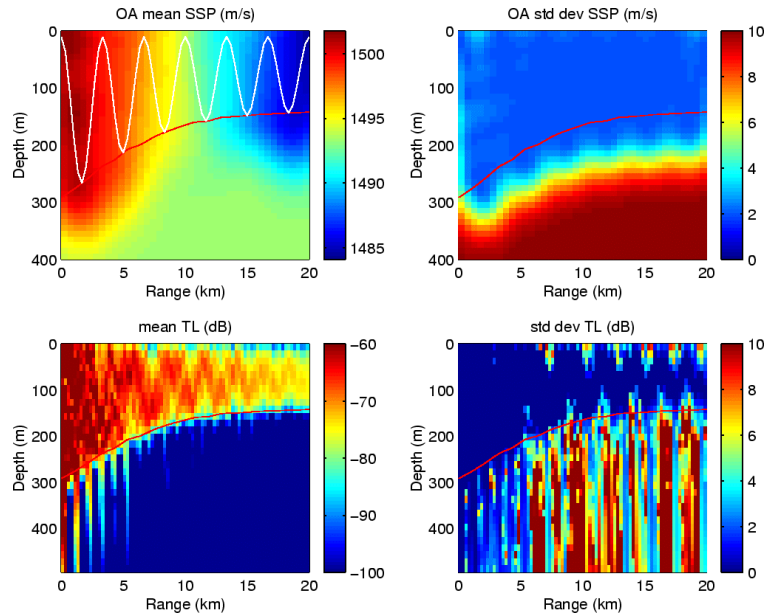
The center piece of the research effort is the GOATS'2000 Joint Research Program (JRP) conducted by SACLANTCEN and MIT with ONR support. Building on the results of the GOATS'98 pilot experiment (Schmidt *et al.*, 1998), the JRP combines a series of experiments, with the two major ones being planned for 2000 and 2002, and modeling and simulation work to explore the potential of autonomous underwater vehicle networks as platforms for new sonar concepts exploring the full 3-D acoustic environment of VSW. The GOATS'2000 experiment will incorporate several AUV's, two of which will be operated by MIT, one equipped with a combined side-scan/subbottom profiler, and one equipped with an 8-element acoustic array, an autonomous acquisition system and 2.4 Gflop of on-board computing power for autonomous processing and adaptive control. The first vehicle will be used as a rapid environmental assessment platform and as a bi-static source platform, which together with fixed parametric source capabilities will be used to insonify the seabed. The second AUV will be used for sampling the 3-D acoustic field either using fixed or adaptive survey patterns, and as a testbed for adaptive response to target detection.

The acoustic modeling effort is centered around the new OASES-3D capability developed at MIT (Schmidt and Lee 1999). OASES-3D provides wave-theory modeling of the full 3-D acoustic environment associated with mono- and bi-static configurations in VSW with aspect-dependent targets and reverberation features. OASES-3D is being expanded to incorporate environmental acoustic features specifically associated with bi-static sonar concepts in shallow water, including aspect-dependent target models, seabed porosity, and scattering from anisotropic seabed roughness and volume inhomogeneities.

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The environmental assessment is critical to advanced sonar concepts and is achieved by combining the Autonomous Ocean Sampling Network (AOSN) (Curtin et al. 1993) with a nested modeling and assimilation framework centered around the Harvard Ocean Prediction System (HOPS), nested within available basin-scale models.

WORK COMPLETED



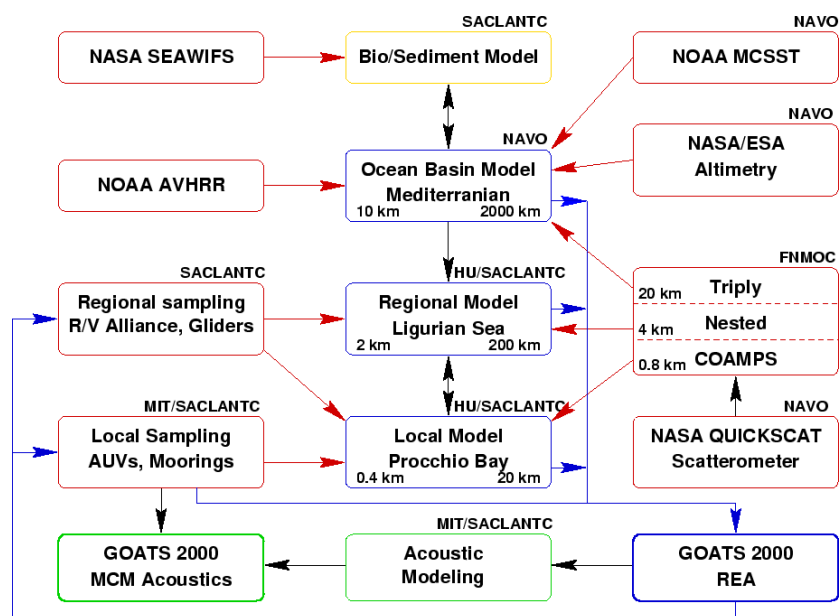
A new numerical tool has been developed for simulating the uncertainty of acoustic predictions in ocean environments with sparse sampling of the sound speed, e.g. as performed by AUVs or more traditional CTD or XBT casts. A Matlab user interface is coupled to C++ modules performing objective analysis based on a priori statistics of the ocean environment and a user-defined sampling strategy. As an example the two upper plots above show the sound speed and its uncertainty, estimated from CTD measurements by an AUV during a 'yoyo' survey in a virtual ocean, generated by the Harvard Ocean Prediction System by assimilating data from the Shelf Break PRIMER experiment off New Jersey in 1996. Realizations of the estimated ocean are then generated, and the associated acoustic field is predicted and averaged, with the lower two plots showing the mean transmission loss and the associated error estimate.

An Ocean Engineer thesis has been completed in FY99 investigating theoretically and experimentally the performance of acoustic navigation systems in shallow water, with specific emphasis on the enhancement provided by coded sequences (Evans 1999).

We continue to analyze the rich tomographic data set collected during the Haro Strait PRIMER effort in 1996. Current emphasis is on using the reciprocal acoustic modem signals transmitted between two of the moorings over an extended tidal period. Using the arrival matching algorithms developed earlier (Deffenbaugh 1997) together with a model of the array dynamics in current, robust estimates of the current profile are achieved. This work is expected to be completed with an MS thesis in FY00.

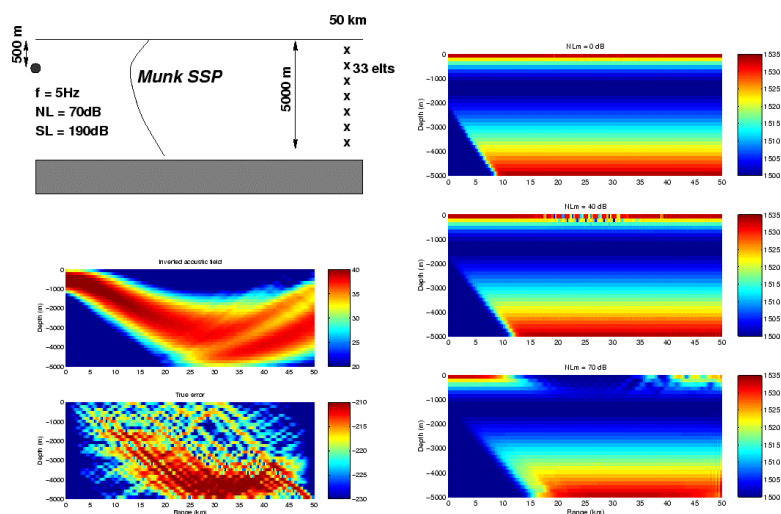
On the experimental side the preparation for the GOATS'2000 experiment in Procchio Bay, Elba in Sep-Oct 2000 is well underway. An extensive environmental assessment survey of Procchio Bay will be performed using R/V Manning during a 2-week cruise in Oct. 1999. The interfacing between the AUV control computer and the acoustic acquisition system has been upgraded to allow control of the data

recording either autonomously by the vehicle control or remotely through the RF or acoustic modems. In collaboration with Bluefin Robotics and Datasonics a second AUV is being equipped with a combined sidescan/sub-bottom profiling system which will be used for environmental assessment in GOATS`2000.



The planning of the MEANS (Multi-scale Environmental Assessment Network Studies) component of GOATS`2000 has been initiated with a kick-off meeting at SACLANTCEN in Oct. 1999. The layout of the nested environmental sampling, modeling and data assimilation is shown above. The Harvard Ocean Prediction System will be nested within NAVOCEAN basin-scale models and COAMPS to provide real-time, local and regional environmental forecasts. The regional and local sampling will be performed using GOATS AUV resources, and available floats, bouys etc.

RESULTS



A new data assimilation formulation of the acoustic tomography problem has been developed, consistent with the traditional ocean data assimilation concept of ocean forecasting (Elisseeff and Schmidt 1999). This Acoustic Data Assimilation (ADA) concept represents the acoustic field and the sound speed as state variables on a common grid. The coupling between the acoustic field and the sound speed, e.g.

using the parabolic equation (PE) formulation is then rewritten into a dynamic model with finite uncertainty with prescribed spatial and temporal correlations. Similarly the dynamics of the sound speed is described in dynamic form, again with an uncertainty term with known statistics. A global minimization of the coupled dynamic equations and the associated acoustic and non-acoustic measurement models then yields a simultaneous estimate of the sound speed and acoustic fields, together with their error estimates. The figure shows a benchmark problem where a narrow-band 5 Hz acoustic signal is recorded on a vertical array in an ocean with a Munk sound speed profile. The color plots to the right show the sound speed estimates for three different levels of ambient noise, while the plots to the left show the estimate of the acoustic field and its error distribution assuming a 70 dB ambient noise level, corresponding to the lower right sound speed estimate. Clearly the errors in the sound speed estimate at the surface are consistent with the convergence zone nature of the acoustic field.

IMPACT/APPLICATION

The long-term impact of this effort is the development of new environmentally adaptive sonar concepts for VSW MCM, which take optimum advantage of the mobility, autonomy and adaptiveness of the AOSN. For example, bi- and multi-static, low-frequency sonar configurations are being explored for buried mines in VSW, with the traditional high-resolution acoustic imaging being replaced by a 3-D acoustic field characterization as a combined detection and classification paradigm, exploring spatial and temporal characteristics which uniquely define the target and the reverberation environment. The MEANS component will explore the potential for providing accurate and reliable real-time environmental estimates at the multiple scales involved in MCM operations.

TRANSITIONS

The GOATS AUV effort has been and is conducted by the MIT Sea Grant AUV Laboratory, in part funded by this project and the AOSN MURI. A new AUV enterprise, Bluefin Robotics, is a spin-off from the MIT Laboratory, and is currently developing a new Odyssey III Battlefield Preparation AUV for ONR, building in part of experience from the GOATS'98 experiment (Schmidt *et al.*, 1998).

The 3-D acoustic models for VSW MCM environments developed under GOATS are being integrated in a multi-AUV simulation capability developed by the MIT Sea Grant AUV Laboratory and Bluefin Robotics under the ONR project (Code 321TS) "Sensor and Operational Tradeoffs for Multiple AUV MCM" (N00014-99-1-0851). Also, the simulation capability is being utilized and augmented under the ONR SBIR (code 321OE) "USBL Positioning of Littoral Swarm Systems" (N00014-97-C-0288) in collaboration with IS Robotics.

RELATED PROJECTS

This effort is part of the US component of the GOATS'2000 Joint Research Project (JRP) with the SACLANT Undersea Research Centre. The MIT GOATS effort is funded jointly by ONR codes 321OA (Simmen), 321OE (Swan), 321TS (Jacobson), and 322OM (Curtin).

The GOATS effort is strongly related to the ONR Autonomous Ocean Sampling Network (AOSN) initiative. Thus the GOATS'98 experimental effort was funded in part by the AOSN MURI, (PI: J. Bellingham). In terms of the fundamental seabed penetration physics there are strong relations to the High-Frequency Bottom Penetration DRI (PI: E. Thorsos). This effort also builds on acoustic modeling efforts initiated under the Sea-Ice Mechanics Initiative (SIMI), and continued under funding from ONR code 321OA (Simmen). In regard to the environmental assessment, ocean modeling and assimilation

component there are strong ties to the LOOPS partnership (PI: A. Robinson) funded by the NOPP, the ONR funded HOPS effort (PI: A. Robinson), and the Haro Strait PRIMER experiment (PI: H. Schmidt, D. Farmer, and J. Bellingham).

The acoustic navigation work (Evans 1999) has been performed in close collaboration with the REMUS AUV group at Woods Hole Oceanographic Institution.

With funding from the Sea Grant College program, a regional New England effort involving MIT, WHOI and URI is developing a new rigid mooring concept with GPS sensor tracking for long-term VSW acoustic experiments, e.g exploring reverberation and ambient noise statistics, and navigation and tomography networks for littoral environments.

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